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Power Quality Compensation in Distribution System based on Instantaneous Power Theory and Recursive Fuzzy Proportional-Integral Controller

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Article Info	ABSTRACT
	In this paper, the power quality compensation problems such as current harmonics and system load's reactive power are considered. In this context, we use static distribution synchronous compensator to inject compensation current into the system, which its reference current signals have been derived from the instantaneous power theory. To improve the current control operation and fast tracking of reference signals, a PI recursive controller has been used which is able to reduce to zero tracking error compared to its conventional type. The performance of the controller is delayed for a period; to overcome this problem, the phase rules have been used to adjust the controller parameters to increase the control performance speed. Finally, in simulation we used Matlab / Simulink software, which has been proven to be better than conventional PI controller-based compensation for power quality.

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1. INTRODUCTION

With the development of electric power industry and the rise of non-linear loads, there have been problems such as current harmonics in power distribution systems, which led to the problems such as transformer heating and saturation, influence on the network voltage, and sensitive loads, etc. Thus, in recent years in order to solve these problems, some research has been done to improve the power quality of the distribution system. The instantaneous power theory [1] is one of the most common theories used to improve the quality of power distribution system, which has been considered in this paper. In this theory, the instantaneous powers of current harmonics and reactive powers are derived, and are compensated by active filters [2] or other compensation distribution systems including D-STATCOM [3]. Three-phase converters of switching signals are produced by using the reference signal compensation and through current controllers such as proportional integral controller (PI) and conventional hysteresis. Several ideas have been proposed in the literature in order to improve the performance of the current controller. For example, in reference [4] frequency division control method is used to create a resonance in current harmonic frequency to enhance the efficiency of control, and also to compensate the system delay.

In reference [5], we used the adaptive hysteresis band to control the reference current. Since the rate of current reference has been changed, therefore switching frequency is varied by an ordinary hysteresis, causing the difficulties in filtering, noise and electromagnetic interactions. In adaptive hysteresis switching technique, the bandwidth changes according to the rate of change in the reference current, which causes the switching frequency to be fixed.

In this paper, a PI recursive controller has been used to control the current, and the controller parameters are dynamically changed based on the phase rules, to improve the performance of the compensator in tracing the current references. In the following we discuss the principles of the compensation of power quality by using this plan. Then the basis of the PI recursive controller and performance of the phase rules will be considered. Finally, the efficiency of the system will be shown using Matlab / Simulink simulation software.

2.   THE STRUCTURE OF THE PROPOSED SYSTEM

The structure of the proposed system and its connection circuit are shown in Figure 1. Three-phase currents for compensating the positive and negative components of current harmonic frequency source and reactive power are extracted by using the instant power theory. In this project a two level tripods voltage source inverter (VSI), is considered as the D-STATCOM. The voltage source inverter is formed by input keys isolated bipolar transistor which operates by a PWM switching project. PWM signals are created by phase PI controller recursive input and also measured by reference to current D-STATCOM. The capacitor which is located near the DC inverter three-phase converters is charged by the true power of the network.
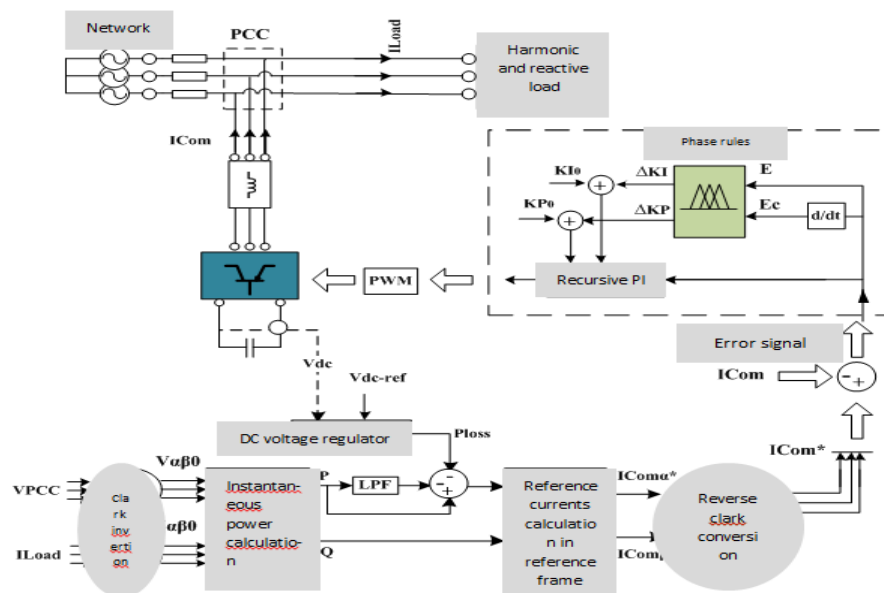

Figure 1. the structure of proposed compensator for distribution system power quality or recursive PI control

3.   COMPENSATOR CONTROL
3.1. The Instantaneous Power Theory

Several control schemes have been cited in articles to extract the current harmonics and reactive loads, including the instantaneous reactive power theory (IRP), the power balance theory, the theory of synchronous reference frame, a theory based on symmetrical components, and so on. In this paper, we have used the method of IRP [6] for this purpose. This theory is based on a conversion of three-phase components to two-phase components in $\alpha\beta0$ frame, and calculation of real and reactive powers in the same frame.

Current harmonics and reactive loads are measured by applying the voltages at PCC, which calculate the load currents and DC bus voltage three-phase inverter. Block diagram of the instantaneous power control method is shown in Figure 2. In Figure 2 it can be seen that the real currents of loads can be calculated after converting the three-phase to two-phase voltage and current. Then in the block of, "Selection of powers to be compensated" the real power fluctuations caused by harmonic components and component current which are negative, isolated from the DC component in order to be injected to the network by the compensator. Total reactive power loads (oscillatory component and dc) should also be produced by the compensator. Finally, harmonic compensation reference current and reactive power are obtained by inverse transform of the system from two-phase to three-phase.
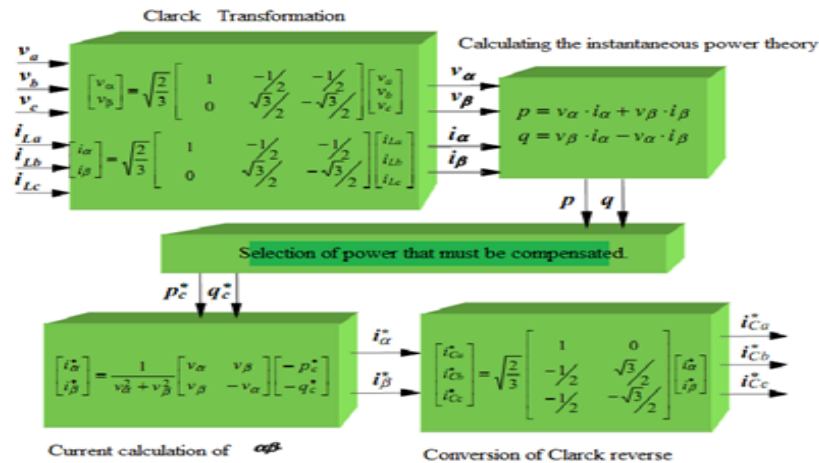
Figure 2. The diagram of instantaneous power theory

It should be noted that in the block of, "Selection of power to be compensated" the required real power to charge of dc capacitor should be considered to absorb the energy from ac network. This can be seen in Figure 1 as Ploss.

3.2. Feedback Fuzzy PI Controller

The quality of the current control ring has a significant impact on compensator performance. The conventional PI current controller is able to endure the tracking error of the reference signal, and make it zero, which a DC signal or a variable signal is slow with the changes. But when the reference signal is a sinusoidal alternating variable with rapid changes, the conventional PI controller recursive has some limitations. So in this paper, a PI algorithm has been used to adjust the point to point. PI controller recursive is equivalent to n which work together in parallel and are capable of enduring error sinusoidal signal control and completely make it zero.

The recursive algorithm can be expressed as follows:

$$u_c(k) = K_p e(k) + \sum_{i=0}^{C} K_I e(k - iN)C \tag{1}$$

$u_c(k)$ **and** $e(k)$ **are the** output value of the PI controller and the sampling error of a sample, K, and N the number of samples in one cycle of K_P and K_I, and the coefficients are proportional and integral. This algorithm, at the same time in each cycle of the tracking error takes integral. In order of digital impellent of this algorithm, we can express the output control $out(k)$ in this form:

$$out(k) = out(k - N) + K_P[e(k) - e(k - N)] + K_I e(k) \tag{2}$$

$(k - N)$ is K sample of pervious cycle. According to Equation (2), it can be observed that PI algorithm, has the previous cycle data in its memory, which guarantee the signal tracking error by zero. However, the dynamic performance is always slow and is responded by one cycle delay. Therefore, to improve the dynamic performance and resistant of the system, a control algorithm must be made. In this paper, we used a phase rule to dynamically adjust the control parameters [7]. Suppose that the phase set of U2, U1, EC, E for ΔKP, ΔKI, Ec are $\{NB, NS, O, PS, PB\}$sets. Rule ΔKP is for that the controller has a quick controlling function to speed up and reduce the tracking error. The integral controller of ΔKP is used to eliminate the tracking error and improve the behavior. Based on the above analysis, rule controls of ΔKI and ΔKP can be obtained in Table 1 and Table 2.

Phase logic steps are as follows:
a. Fuzzification

$$E = [\lambda_1 E(k)]EC = [\lambda_2 E_c(k)] \tag{3}$$

b. Fuzzy decision making
c. Defuzzification

$$\begin{cases} K_P(k) = K_{P0} + \lambda_3 U_1(k) \\ K_I(k) = K_{I0} + \lambda_4 U_2(k) \end{cases} \tag{4}$$

That X reflects the correct value of x, λ1 and λ2 are fuzzy coefficients and λ3 and λ4 are Non-fuzzy coefficients. The values of these parameters λ1, λ2, λ3 and λ4 can be selected based on the actual state.

Table 1. Parameter setting rules of ΔK_P

E_C / E	NB	NS	0	PS	PB
NB	PB	PB	PS	PS	0
NS	PB	PS	0	0	NS
0	PS	PS	0	NS	NS
PS	PS	0	NS	NS	NB
PB	0	NS	NS	NB	NB

Table 2. Parameter setting rules of ΔK_I

E_C / E	NB	NS	0	PS	PB
NB	0	0	NB	NS	0
NS	0	NS	NS	0	0
0	0	NS	PS	NS	0
PS	0	0	PS	PB	0
PB	0	PS	PB	0	0

Actual and reference flow-D-STATCOM can be compared with each other, and phase error signal by a proportional-integral controller rebound fuzzy strengthen, and passed the block pulse width modulation (PWM) switching signals to produced D-STATCOM inverter.

4. SIMULATION RESULTS AND ANALYSIS

For the efficiency of the system we used Matlab / Simulink software for the simulation. The performance of the proposed scheme has been studied to compensate reactive power and current harmonics rather than the ordinary control.

4.1. First Scenario: The System Performance in Harmonic and Reactive Power Compensation

In this scenario, the distribution systems with reactive and harmonic loads have been simulated at 0.5 seconds. The proposed compensator is switched to the circuit at 0.15 second and performs the compensation function. Figure 3 shows the output results of this scenario. In the figure, the system's three-phase voltages, load currents, reference currents, injection currents of compensator, and DC shane bus voltage compensation, respectively have been shown.
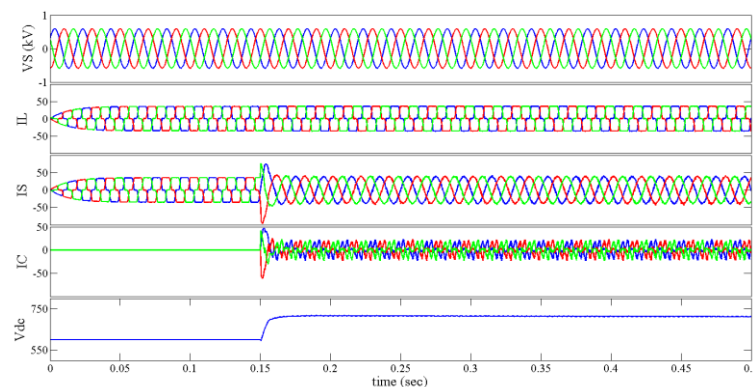

Figure 3. Simulation output in the first scenario

With compensation function, harmonic distortion factor of the three-phase currents has been decreased from the values of 22.07, 22.12 and 22.11 to 3.26, 4.37, 4.22 respectively, which is compatible to IEEE-519 standard which its permissive THD of current is 5%. It also can be seen that the DC bus voltage has been established with reference values. Reference currents waveform and its voltage have approximately the same phase and absorption reactive power is compensated by the source too.

4.2. Second Scenario: Comparison of Conventional PI Controller and Phase PI Return.

The second scenario is considered to compare the performance of two controllers to c static synchronous compensator. So this compensation is simulated once with the conventional PI controller and with a fuzzy PI controller in return. The tracking error of reference currents signals for two controllers is shown in Figure 4.

As can be seen, PI controller is able to reduce the steady tracking error signal to zero. But as mentioned earlier, this controller acts as a delay period, to solve this problem fuzzy rules have been employed for adjusting the proportional and integral parameters. Figure 5 shows the dynamic changes in the parameters K_p and K_i compensation circuit switching. It is observed that the K value increases the speed control to increase output and reduce tracking error, the K_i value is reduced immediately to decrease its impact, and lead not to a tuck there. K_i value increases gradually to improve its effectiveness and reduce the steady state error. The values of these two parameters will be established at a level of stability.
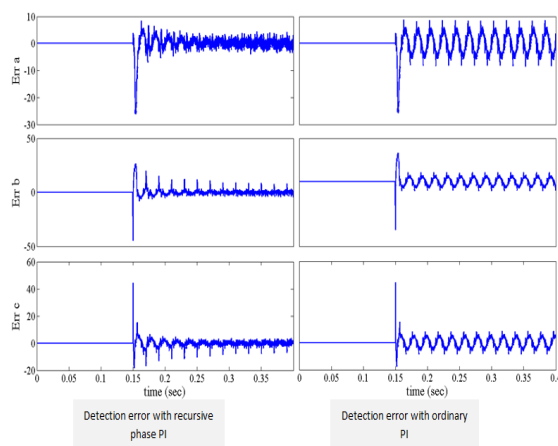

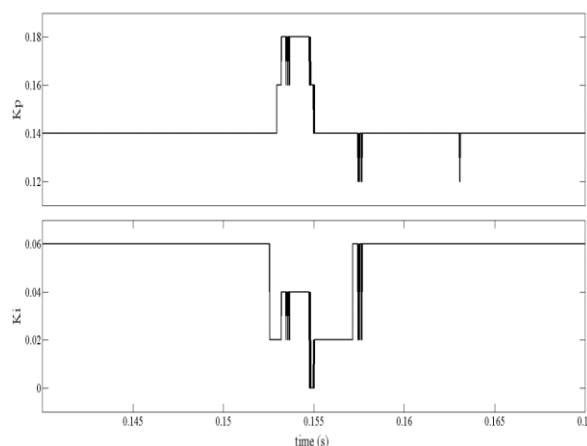Figure 4. Three-phase reference currents detection error or two types of controllers (the second scenario)

Figure 5. The variations of recursive PI control parameters based on phase rules at the moment of switching of compensator to the circuit

5. CONCLUSION

In this paper was studied the compensated three-phase power quality, distribution systems by using static synchronous compensator distribution. To extract the reference signal compensation, three-phase power instantaneous were used, and finally to improve flow control and access the fast-tracking software and reference signals, a controller proportional - integral recursive algorithm based on the fuzzy has been used. For the efficiency of the system we used Matlab \ Simulink software for simulation.

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